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# Major sudden stratospheric warming in Antarctica: the relationship between the polar vortex and ozone in the countervortex.

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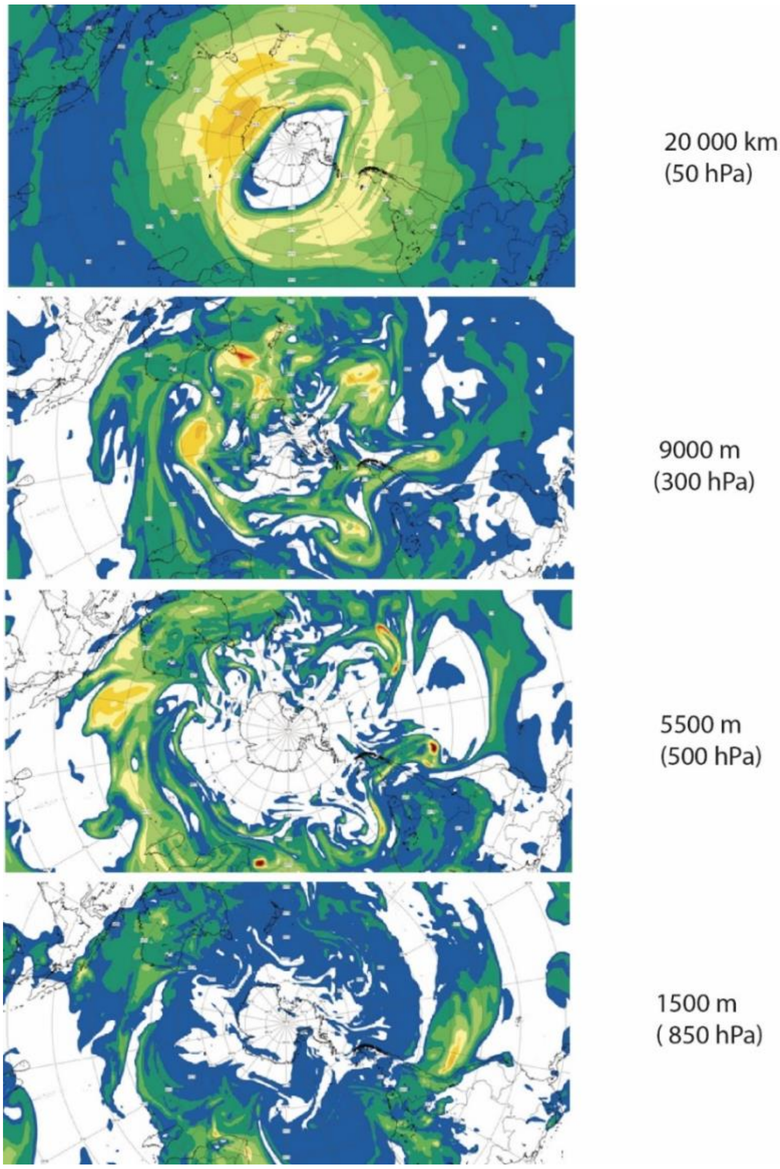
## INTRODUCTION

The ozone layer is normally located between 10 and 40 km above sea level. Natural ozone (excluding anthropogenic pollution) is mainly formed at low altitude by thunderstorms, smoke from forest fires, particularly in the intertropical zone, and above the ice on the large ice caps. The data on the Copernicus website are an excellent complement to our understanding of **Sudden Stratospheric Warming** (SSW). The warming of the complex polar vortex (SCE, 2024) is linked to the destruction of ozone under control by particles imported by solar winds, particularly during periods of high solar activity and especially coronal mass emissions (CMEs).

The classic winter thinning of the ozone layer, also known as 'the hole', is linked to the reaction of ozone with stratospheric chlorine, as after the eruption of Hunga Tunga in 2002, with a very large hole in 2023. This exothermic chemical reaction occurs mainly on the surface of stratospheric ice crystals under the action of solar UV rays in summer or under the impact of the solar particle flux only in winter. It is a natural phenomenon that has existed since the Miocene (the age when Antarctic glaciers were established) (see here). The Antarctic atmosphere is enriched at this time by ice crystals injected into the stratosphere via the polar cyclonic vortex, just as during Hunga Tunga. In winter, the impact of UV is cancelled out and is therefore be attributed to solar particle flux (solar wind). Because of Antarctica's climatic isolation, the ozone destroyed in the ozone layer (10-40 km) would not be replaced by extra-regional inputs.

**OBSERVATIONS**

The CAMS modelling (Figure 1) of 7/10 clearly showed a concentration of atmospheric ozone in the lower stratosphere due to the action of the tropospheric winds, more particularly the polar jet stream, which results from a stratospheric vortex being sheathed by ozone, thickened near the edge and walls of the vortex cyclone. The ozone is pumped by the outer edge of the vortex from the intertropical zones (around 1500m, thunderstorm lower part),




then stirred up by the Antarctic jet stream (Figure 1). There is indeed a connection with the troposphere as a whole and not only polar zones.

*Figure 1: Tropospheric zone supply (orange to green) in the lower stratosphere on 7 October 2024 (Copernicus Atmospheric Model Service / CAMS)*

Our recent observations of 5-8 October 2024 confirm our initial interpretation of the SSW (SCE, 2024) and show that the vortex was compressed by the formation of the countervortex. The winds at the contact between the two were accelerated by a Venturi effect, inducing an elongation of the vortex (Figure 2). These winds reached 418 km/h and were associated with a significant increase in temperature in the accelerated zone (-4°C) and more modest increases in the vortex (-38°C instead of -80°C) and in the countervortex (-27°C) associated with weakened winds from the vortex (343 km/h) and the countervortex. (Figure 3).

The accumulation of ozone is obvious in October 2024, at the level of the anti-vortex (Figures 1 and 2) and a maximum was reached on 8/10/24 according to the already decreasing temperatures and speeds in the vortex-countervortex convergence zone (Venturi effect). These favoured rapid destruction of ozone in the absence of the winter UV radiation (SCE, 2024). The significant ozone destruction in the antivortex can only take place if the solar wind is strong and confined to the Antarctic polar magnetic cone.

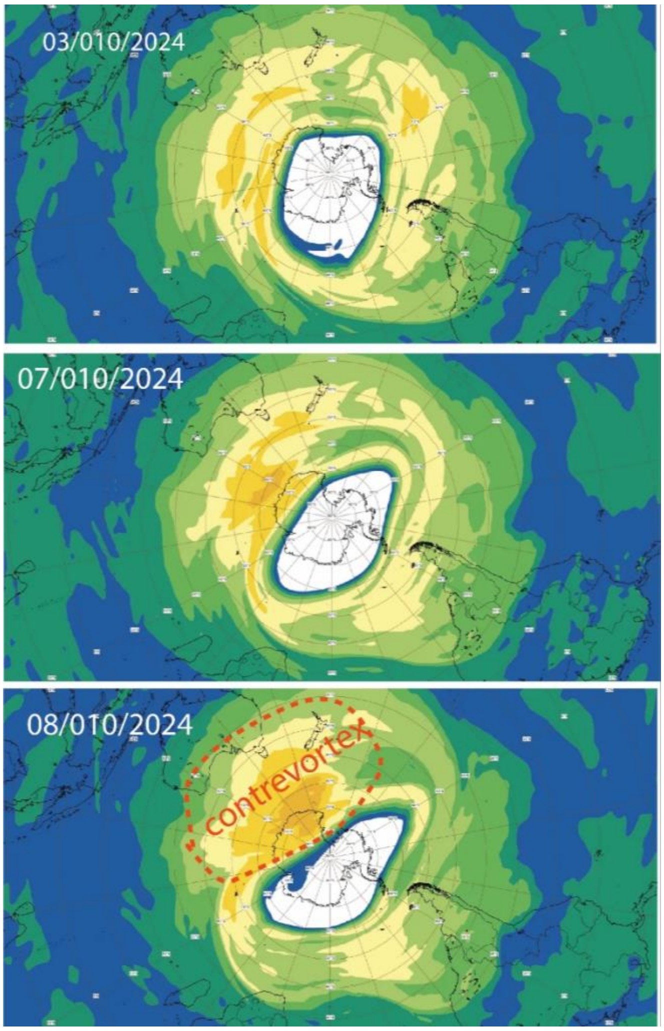



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*Figure 2 : 3-8 /10/2024 The accumulation of ozone is obvious at the level of the countervortex. This pumping is related to peristalsis linked to the rotation of the vortex crushed by the countervortex. Source Copernicus, CAMS). Note that on 8/10, the rotation of the counter-vortex affects the ozone layer.*

In 2024, the winter ozone hole over the southern hemisphere was smaller than usual. Antarctica experienced two sudden low-power stratospheric warming events in July and August 2024. July 2024 temperatures in the stratosphere over Antarctica were generally around -80°C. A series of SSW events occurred in 2024, notably on 7 July in association with a notorious elongation of the vortex: temperatures in the stratosphere at 10hPa climbed to -65°C, generating a record for the warmest winter temperatures observed in the Antarctic stratosphere. The temperature then dropped on 22 July before rising again to -63°C on 5 August.

Temperatures higher than 4°C above the average for July covered large parts of the Antarctic continent, and the thermal anomaly was also observed in southern Australia and Tasmania. For the month of August in Australia, the tropospheric thermal record of 1919 was broken, and associated with forest fires (which the events of 7 July and 5 August 2024 are associated with peaks of solar winds of low magnitudes 680 and 720 km/s.

During the austral winter, two anticyclonic centres formed at the end of June 2024, one to the south of Australia, the other over the south of Tierra del Fuego. These are anticyclones or anti-vortexes, the basic structures capable of generating an SSW (SCE, 2024). A true SSW, with a vortex-antivortex configuration, is a rare phenomenon in the Southern Hemisphere.

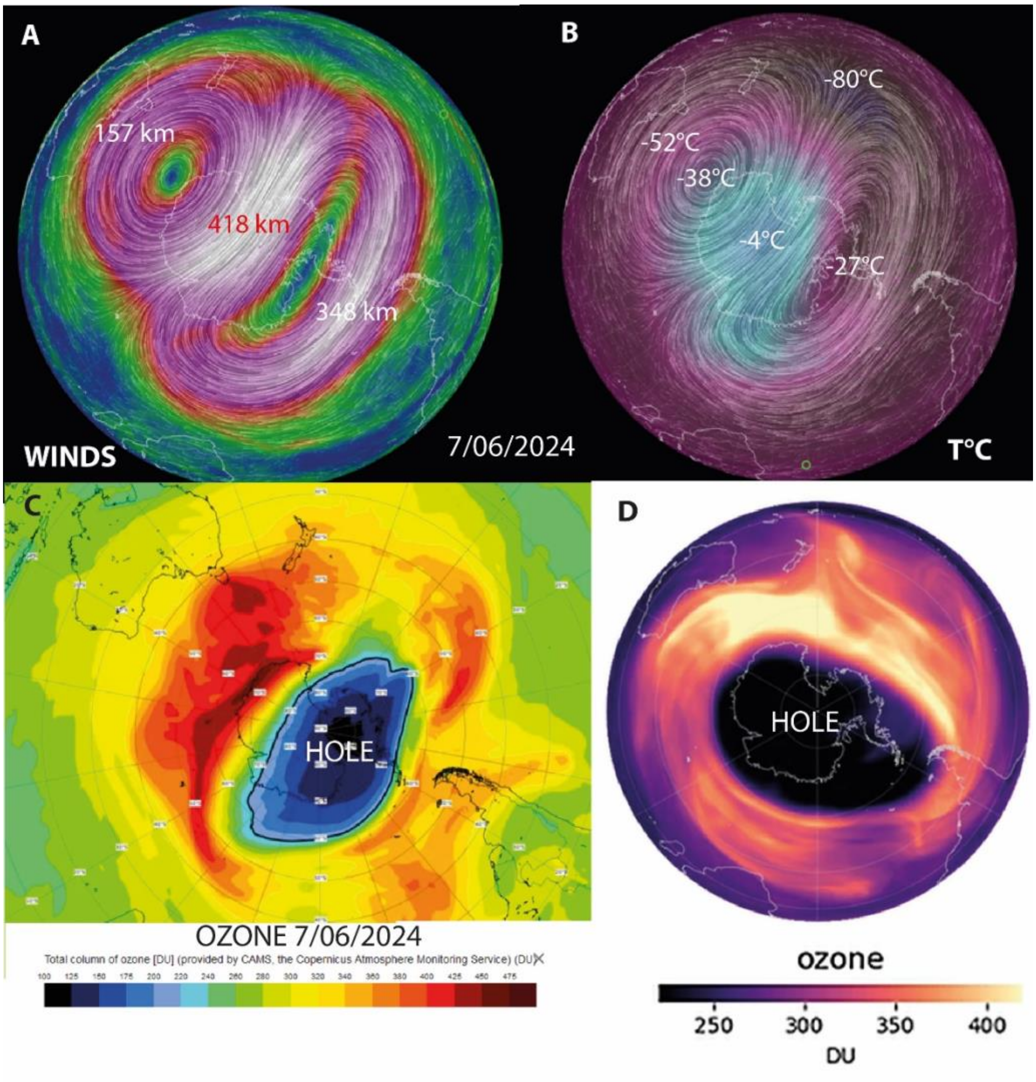


*Figure 3: A) Vortex wind image; B) temperatures (rapid in white, warm in blue) according to https://earth.nullschool.net/; C) total ozone on 7/10/24, Copernicus; D) ozone layer (in yellow) pierced and shaped by the vortex (5 August; NASA). Note the ongoing elongation of the hole (vortex).*

It has just occurred on 7 October 2024 with a temperature of -4°C (instead of -80°C) in the contact zone between the vortex and the anti-vortex, in connection with major solar activity. The phenomenon that developed on 5 October and follows two very close peaks of solar winds during the night of 1 to 2 October (X7.1 CME) is linked to a coronal mass ejection (CME), and the one on 3 October (X9.05 CME), an ejection directed towards the Earth, represents the strongest solar flare of the current solar cycle (cycle 25). The last time we had solar flares larger than this one was in 2017 in solar cycle 2. This is in fact the strongest solar flare in 7 years. The solar wind peak reached the Earth on 4 October 2024 and did not exceed 600 km/s. The accumulation of ozone is obvious in the anti-vortex, which is being pumped up on the vortex side by the concentration of this gas (Figures 2 and 3). This pumping of ozone is linked to peristalsis associated with the rotation of the vortex, which is itself crushed by the rotation of the vortex (Figures 2 and 3C).

**CONCLUSIONS**

To conclude, in 2024, apart from the events described the ozone hole over the southern hemisphere was smaller than in 2023. The formation of the vortex, however small, carries ozone from the lower tropospheric latitudes and that formed aloft over the ice caps towards the stratospheric polar regions. The change in stratospheric circulation during an SSW is systematically associated with the exacerbation of a countervortex, enriched in destructible ozone, under the impact of discharges of fast solar winds loaded with solar particles. In addition to the Venturi heating between the vortexes and countervortexes, the exothermic ozone destruction reaction is responsible for the rapid heating episodes (Figure 4, SCE, 2024).

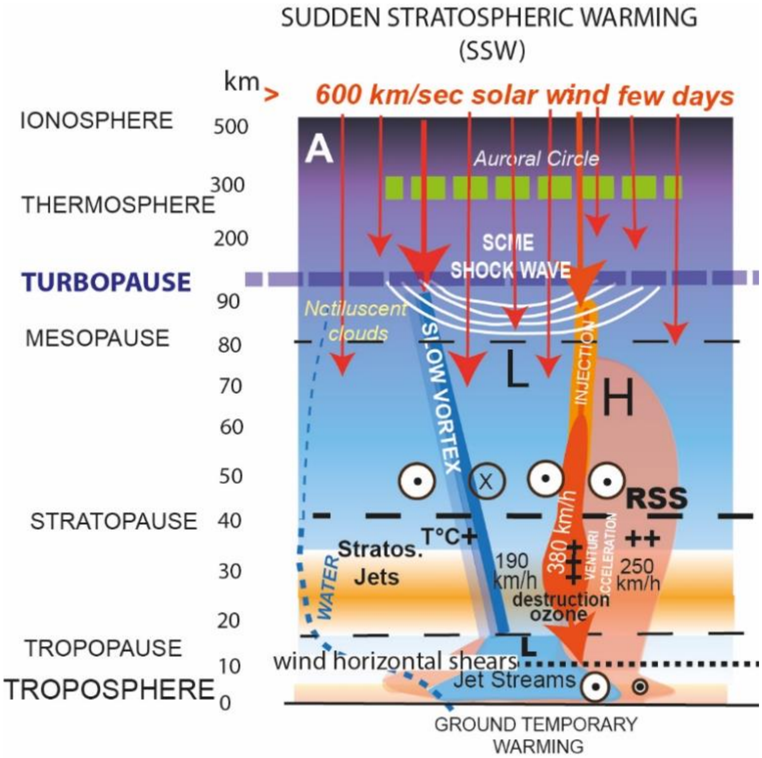


*Figure 4 : Diagram of how a Sudden Stratospheric Warming develop* ( SWW; SCE, 2024)

**This reactive heat is then dissipated towards the lower troposphere, causing unexplained heatwaves until now. Given the longitudinal position of the countervortex, we can expect a severe heatwave over southern Australia, Tasmania and probably the North Island of New Zealand in the next few days. Consequently, SSW is a natural phenomenon, essentially the result of solar activity, but atmospheric pollution linked to human activity can accentuate its intensity.**